NCEMT

National Center for Excellence
in Metalworking Technology

MANTECH Center of Excellence

Operated by

CTC Concurrent Technologies Corporation

For the U.S. Navy Manufacturing Technology
(MANTECH) Program

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Providing Metalworking Solutions to Enable Defense

Transformation

2003 Annual Report

NCEMT

National Center for Excellence in Metalworking Technology

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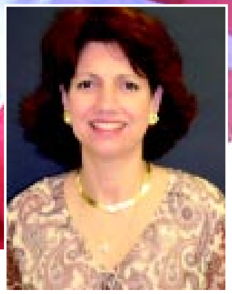


The 21st Century security environment requires that we expand and transform the U.S. Navy's warfighting capabilities, delivering vessels that are faster, stronger and more agile. The nature of open-ocean and littoral missions is changing; ships are being called upon to conduct both traditional combat operations on world seas *and* to fight high-speed, multi-threat missions in shallow waters.

The U.S. Navy Manufacturing Technology (MANTECH) Program is diligent in its pursuit of what President George W. Bush has called "leap-ahead solutions" to support fast-changing U.S. Navy needs. The National Center for Excellence in Metalworking Technology (NCEMT), a MANTECH Center of Excellence, is delivering such solutions and answering America's most demanding technology challenges.

I commend the NCEMT for its record of excellence and for the pioneering contributions you will read about in this publication.

This year, it is my pleasure to welcome a new Program Director for the NCEMT. Daniel L. Winterscheidt is now overseeing the program. Dan is a U.S. Naval Academy graduate and Director of Manufacturing Programs for Concurrent Technologies Corporation, and I know he looks forward to serving the Navy in this important new capacity.

Sincerely,

Adrienne E. Gould
Deputy Director
Navy Manufacturing Technology Program
Office of Naval Research

"I wish to have no connection to any ship that does not sail fast for I intend to go in harm's way." The words of Captain John Paul Jones, who was commissioned senior lieutenant of the Continental Navy in 1775, apply as much today as they did during America's Revolutionary War. U.S. sailors expect to defend and serve their country aboard the finest, swiftest fighting fleet ever known.

To meet these expectations, the NCEMT and its government and industry partners are developing advanced metalworking solutions for ships that must go in harm's way. These solutions are helping provide sailors with increased firepower, stealth and speed, allowing the U.S. fleet to operate where the risk would be too great for other warships.

To advance the development and deployment of reliable, affordable technology that will perform at a moment's notice, the NCEMT continues to deliver comprehensive metalworking advances for naval systems. This annual report details some of those advances, ranging from low-cost, high-performance titanium components for the XM777 Lightweight 155mm howitzer to significantly better ways to manufacture high-demand thermal batteries for sonobuoys and missile systems. Working with industry and government, NCEMT engineers and scientists develop and implement manufacturing solutions for key Department of Defense systems, such as the Joint Strike Fighter, the Advanced Amphibious Assault Vehicle (AAAV), the DD(X) 21st Century Destroyer and the Stryker Mobile Gun System.

At the NCEMT, projects are results-oriented and tightly focused on the transformational mandates of the U.S. Navy and the Department of Defense. This year, we had our own transformation of sorts. Dick Henry transitioned from the directorship that he has held since 1994. On behalf of everyone at the NCEMT, I want to thank Dick for his sincere dedication and outstanding service. As the new Program Director, I look forward to leading the NCEMT in its mission to support the manufacturing and technological challenges of the U.S. Navy.

Much has been accomplished at the NCEMT, and the U.S. Navy's future force will demand that much more be achieved. Our clients, partners and the crews of the U.S. Navy can be confident in the continuity of leadership at the NCEMT—this organization will continue to serve you well.

We began by remembering the words of the Father of the American Navy. In one of history's most famous sea battles, John Paul Jones captaining the Bonhomme Richard, was out gunned and out manned, yet won against an entire fleet. We trust that our sailors will never again be out gunned or unprepared, and you can trust that each day we are working to ensure that the U.S. Navy will continue to be the world's most capable.

Sincerely,

Daniel L. Winterscheidt, PhD
Program Director
National Center for Excellence in Metalworking Technology

Forming

Creating high-tech solutions for high-priority defense projects

The NCEMT is working with government and industry partners to develop advanced forming solutions for weapon-system components associated with key projects, such as the Joint Strike Fighter and the XM777 Lightweight 155mm howitzer (LW155).

Conventional forming processes include forging, rolling, extrusion, drawing and stamping, which have been in use for more than a century in military weapon-system components. New, advanced forming processes currently under development for military needs include flowforming, superplastic forming, laser forming, spray forming and composite fabrication techniques. Numerous components—ranging from fasteners to turbine rotors—are made using a combination of these forming processes. Today's challenge is to rapidly identify new techniques that allow manufacturers to fabricate affordable, high-performance formed parts with the requisite shape, size, microstructure and mechanical properties to properly function in critical applications.

Several NCEMT projects are focused on flowforming, a forming process that enables the manufacture of dimensionally precise, symmetrical, tubular components. Flowforming (also termed 'tube-spinning' or 'flow-turning') is performed by applying power compression to the outside of a spinning cylindrical component. A combination of axial and radial forces from two or more computer-numerically controlled rollers evenly separated around the component deform the material, shaping and reducing wall thickness.

One flowforming project has the potential to reduce the lifecycle expense and improve the performance of U.S. Navy five-inch guns. Approximately 20,000 five-inch cartridge cases are used every peacetime year in U.S. Navy training exercises. Traditionally, the steel cartridge cases have been manufactured using a deep-drawing process that is no longer cost effective. The NCEMT—in conjunction with the Naval Surface Warfare Center Divisions at Indian Head; Dynamic Machine Works, Inc. and Owego Heat Treat, Inc.—has identified a new alloy and a new processing technique.

The NCEMT is working to help reduce the cost of aerospace-forged components for the Joint Strike Fighter engine.

Forming continued

AISI 94B15, a low-alloy steel, has been selected following rigorous testing. New heat-treatment and flowforming processes have been developed to enhance the performance of the cartridge case in firing both standard and Extended-Range Guided Munitions (ERGM)—all while reducing production costs.

Two radically different projects are utilizing similar rotary forming techniques. In one project, Reduced Buy-to-Fly Aerospace Disk Components, the NCEMT is currently developing a new forming process (hot spin forming, also termed hot flowforming) for the aerospace disk component used on the engine of the Joint Strike Fighter. The project is just getting underway.

In another project, the NCEMT is developing new flowforming applications for the manufacture of LW155 cradle tubes. The titanium cradle tube assembly, which weighs 250 pounds, provides structural support to the LW155 cannon assembly and recoil systems. The cradle tubes were originally manufactured by boring out solid billet. Such an approach presented material waste issues. The NCEMT was asked to identify new processing routes that conserve as much material as possible while further reducing costs and meeting project schedules.

As a result, the NCEMT has identified new flowforming options that have the potential to conserve titanium by converting thick tube into thin-gauge tube. Total cost savings of approximately \$13.3 million are anticipated over a five-year period.

Technology transfer is underway. The NCEMT is working with established flowforming vendors to develop dependable, material-efficient techniques for cradle-tube production.

Another significant forming project that the NCEMT recently completed involves forging. To reach the affordability goals of the next-generation F-35 Joint Strike Fighter (JSF) and other military aircraft, the joint Air Force/Navy Forging Supplier Initiative strived to reduce the cost of aerospace-forged components such as airfoils, cases, disks, rings and shafts by 35 to 40 percent. Forgings account for about 34 percent of the cost of the JSF engine.

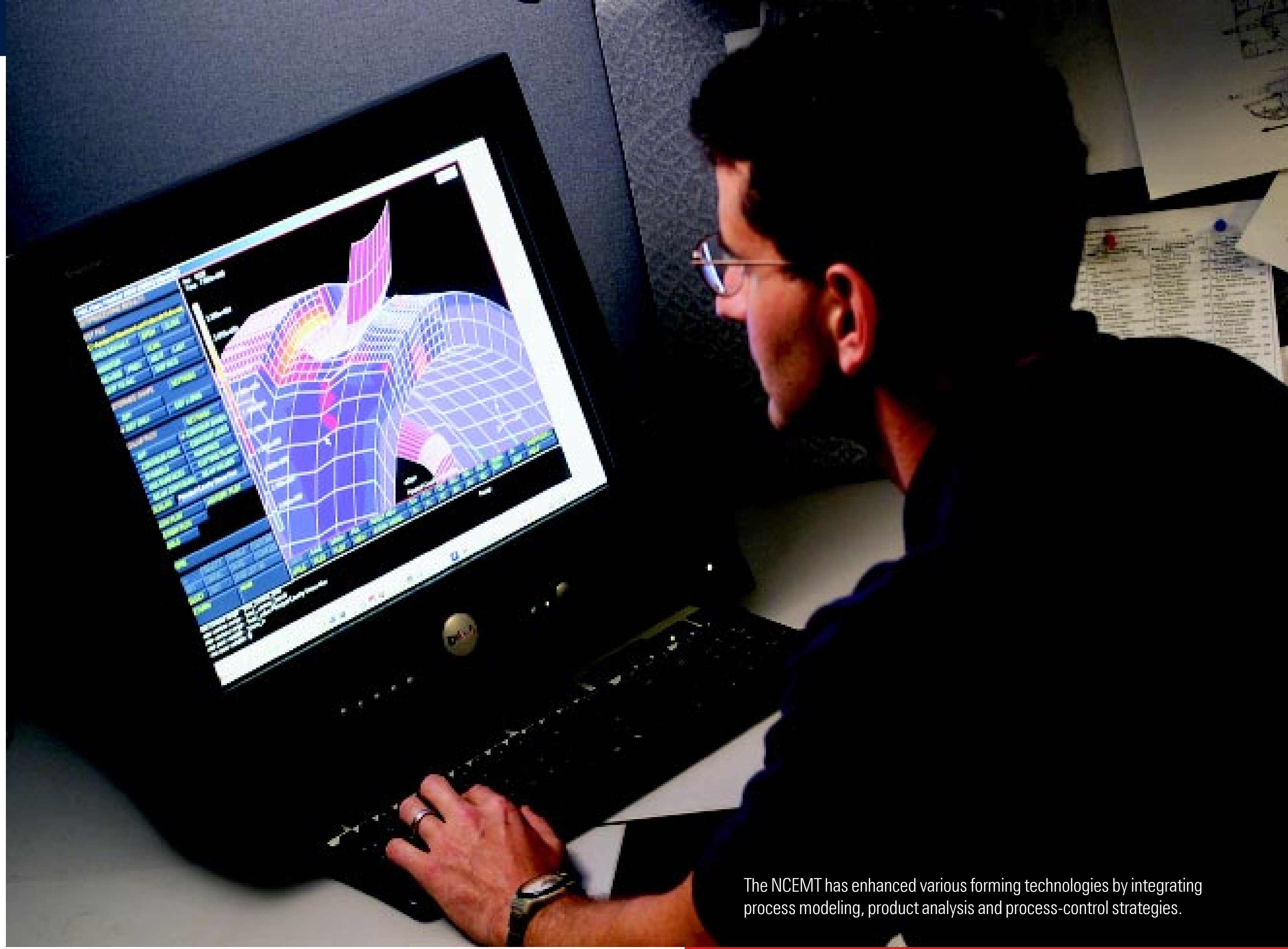
Working with teams led by Pratt & Whitney and GE Aircraft Engines, the NCEMT has provided technical support to develop new process technologies and improvements using deformation trials, process modeling, materials testing and characterization.

New technologies developed through this Forging Supplier Initiative program are expected to achieve cost savings of about 15 to 20 percent for large engine disks and 15 percent for ring-rolled cases.

New ring-rolling design tools developed for forging suppliers represent a significant achievement. The Air Force and Navy are expected to save \$1.44 million in five years on ring-rolled engine cases by adopting these design tools and associated manufacturing practices.

The NCEMT, with support from its government and industry partners, has transitioned tools and technologies developed through the Forging Supplier Initiative program to industry. Implementation of this and other new technologies demonstrates an integrated strategy aimed at making the U.S. forging supplier base more competitive.

The Scanning Electron Microscope/Energy Dispersive Spectrometer allows NCEMT scientists to perform microstructure analysis—viewing materials at the atomic level.



The NCEMT has enhanced various forming technologies by integrating process modeling, product analysis and process-control strategies.

Another example of NCEMT expertise in the area of forming involves the sophisticated application of roll forging (also called ring rolling) for the U.S. Marine Corps Advanced Amphibious Assault Vehicle (AAAV). The NCEMT conducted a study to identify the lowest cost process to manufacture the flat, double-angle, cross-section turret ring for the AAAV. Roll forging was determined to be the most favorable method for fabricating the component. However, AL-Cu-Mg alloy 2519, the vehicle's main structural alloy, had never been roll forged.

The NCEMT identified optimized 2519 forging parameters by hot working simulation using hot torsion and uniaxial compress testing. Using the data generated, the NCEMT and Rotek, Inc. successfully manufactured several prototype 2519 turret rings—establishing a new product form for 2519. The properties of the turret rings significantly exceeded the minimum 2519-T6 tensile requirements. The prototype turret rings cost 55 percent less to manufacture than the baseline cost to machine the rings from plate stock. This process and vendor path are now available to the AAAV Program, and the forging process parameters identified are currently being used to produce AAAV 2519 inlet housing forgings.

Flowforming advantages

Flowformed materials and parts typically have:
- Outstanding surface finishes
- A fine grain size
- Good ductility
- Complex geometric shapes
- A slow rate of work hardening
- An adequate spread between yield and ultimate strengths
- Improved strength despite very large reductions
- Thin, precise cross-sections

The smooth-surface, sub-scale titanium ingot shows the level of NCEMT improvement in the area of plasma arc cold hearth melting.

NCEMT's team is first to cast titanium slabs using plasma arc cold hearth melting

Driven by mandates from the Pentagon, based on a need to develop ground combat vehicles and weapons that are dramatically lighter than the current fleet, the NCEMT has been tasked to develop a plasma arc cold hearth melting process to manufacture titanium into slabs that can be directly rolled into armor plate. The project, conducted for the U.S. Army Armament Research, Development, and Engineering Center (ARDEC) and the U.S. Army Tank Automotive Research, Development, and Engineering Center (TARDEC), is managed by the NCEMT. The NCEMT and RMI Titanium Company have met the Pentagon's challenge by casting single-melt titanium into rectangular slabs with increased material yield, mechanical properties comparable to those of conventionally processed material, and significantly reduced cost. This is the first time that titanium slabs have been successfully cast using plasma arc cold hearth melting.

The NCEMT and its partners have demonstrated that titanium slabs cast by the single-melt plasma arc process are suitable for armor—a finding that can greatly enhance the cost savings and functionality of a variety of U.S. weapon systems.

Casting

Advancing the MANTECH titanium casting knowledge base

Casting is the process of shaping molten metal into a particular mold that contains a cavity of a desired shape. Because castings are an integral and critical part of many weapon systems, high-quality cast parts in increasingly complex shapes are a major requirement of the U.S. Navy, Department of Defense and commercial clients. The use of computer simulation in the casting process not only helps produce defect-free castings, but also reduces development time and production cost. The NCEMT has established an extensive capability in casting process modeling, a competency that enables the prediction of potential defects and the selection of optimum manufacturing methods.

Overcoming inherent challenges in the casting of titanium is a major focus of NCEMT efforts and a major success story. Titanium is a lightweight, corrosion-resistant, high-performance material that is extremely desirable for use in weapon systems. Unfortunately, titanium is expensive and difficult to process. However, the NCEMT has made great strides in adding to the MANTECH titanium casting knowledge base.

Working with the Lightweight Howitzer Joint Program Management Office (JPMO) of Picatinny Arsenal, New Jersey; BAE Systems of the United Kingdom; and a titanium foundry, the NCEMT is developing single-piece investment cast spades for use on the XM777 Lightweight 155mm howitzer (LW155). This innovation is expected to save approximately $27 million.

The spades, which stabilize the LW155 during firing, are fabricated by machining and welding 60 individual elements—an expensive, labor-intensive task. The NCEMT and its partners are working to reduce the parts count of the spades from 60 to one by replacing elements with a near-net-shape spade casting. In addition, optimized casting processes, which are aided by computer simulations performed by the NCEMT and its partners, will result in the production of dimensionally stable, shrinkage-free spades.

The NCEMT is identifying new manufacturing processes that will reduce costs and enhance the performance of the U.S. Marine Corps Advanced Amphibious Assault Vehicle (AAAV).

A titanium gun pod designed at the NCEMT will reduce the weight of the Stryker Mobile Gun System.
Inset: Stryker Mobile Gun System under development by General Dynamics Land Systems.

Another challenging LW155 component is the saddle, which connects the elevating mass (including the cradle that houses the cannon and recoil system) to the howitzer's lower carriage. Saddles are fabricated by machining and welding together more than 110 individual subcomponents. The NCEMT is working with the JPMO, BAE Systems and a titanium foundry to create a single-piece investment cast saddle that will save the JPMO approximately $5 million over five years.

Lowering manufacturing costs while improving fracture toughness and reliability are aims of a project whose hardware is about to be field-tested by the U.S. Marines. The NCEMT used investment casting and forging methods to produce low-cost, near-net-shape track blocks for the U.S. Marine Advanced Amphibious Assault Vehicle (AAAV). Under TARDEC sponsorship, NCEMT engineers utilized high-oxygen, low-cost revert for casting track blocks with up to 0.25 weight-percent oxygen.

Having attained high-strength, corrosion-resistant blocks, the NCEMT delivered cast-track segments (with 0.19 and 0.25 weight-percent oxygen) as well as forged-track segments to the AAAV Program Office for further testing. Although the AAAV is not currently baselining a titanium track, the fabrication process parameters developed and mechanical properties generated help pave the way for increased use of low-cost titanium alloys.

One of the Army's transformational goals is to be able to deploy brigade combat teams anywhere in the world within 96 hours. In support of the Light Armor Vehicle Brigade Combat Team Program, the NCEMT has designed and developed a lightweight, two-piece cast titanium gun pod for the Stryker Mobile Gun System. The Stryker is an eight-wheel-drive combat vehicle that must be light enough to be deployed by C-130 cargo aircraft. The NCEMT designed a gun pod weighing 140 pounds less than the original weld-fabricated steel gun pod—a 28 percent weight savings. In addition, the parts count has been reduced from 40 to two.

The NCEMT is supporting the development of the U.S. Navy's Standard Missile 3 (SM-3) by commercializing the process of electro-discharge machining (EDM) of rhenium. Inset: Redesigned feed shoe, tooling, wear plate and parts removal system used in the manufacture of thermal batteries.

Powder Metallurgy

Because precision counts

Enhanced survivability. To-the-minute reliability. Maintaining the U.S. Navy's unparalleled combat capability means that even the smallest component of a sophisticated weapon system must be of superior quality. To ensure precision in the battlefield, the NCEMT and its government and industry partners are working to deliver precise, innovative solutions to our nation's warfighters.

To achieve defense goals of improved endurance, affordability and availability, components must display improved mechanical and chemical properties. Powder metallurgy has the potential to increase strength and wear-resistance, reduce waste and offer long-term performance reliability in critical applications.

Powder metallurgy is an automated manufacturing method that uses pressure and heat to convert powdered metals into precision parts. Ferrous materials are most commonly used; however, powder metallurgy can accommodate any material available in a powder form. Near-net-shape parts can be produced, which save time and money while eliminating or minimizing scrap losses. Powder metallurgy is an efficient process that utilizes 97 percent or more of the raw material in the finished part, making the process environmentally and economically desirable.

Modern powder metallurgy began in the early 1900s when a filament for electric light bulbs was fabricated from tungsten powder. Today, the NCEMT is using sophisticated new powder metallurgy technologies to reduce costs, increase production and improve the quality of thermal batteries.

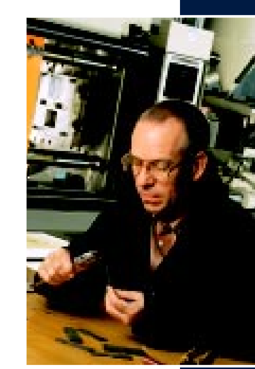
The military uses thermal batteries to power sonobouys, guided artillery, missiles, guidance systems and countermeasure devices. Battery costs were limiting the number of sonobouys that could be purchased and deployed, and manufacturing processes could not meet production requirements.

To identify the problems, the NCEMT worked with the U.S. Navy's PMA-264 Airborne Anti-Submarine Warfare, Assault and Special Mission Programs, the Naval Surface Warfare Center Carderock Division and the battery manufacturers. The NCEMT redesigned the material feed system and tool set, the cell component removal and accumulation system, and a number of other parts and procedures. These innovations improved material utilization, press efficiency and cell component quality, thus reducing costs, increasing production and improving quality of thermal batteries.

As a result of these powder metallurgy process improvements, thermal battery users can potentially achieve savings of 22 percent. This translates into a cost avoidance of $30 million over a five-year period for the sonobuoy program alone. Moreover, approximately 7,400 more batteries can be produced each month because of these process improvements.

In another project, the NCEMT is supporting the development of the U.S. Navy's Standard Missile 3 (SM-3) by commercializing the process of electro-discharge machining (EDM) of rhenium. With guidelines established under the MANTECH Program, nearly any EDM manufacturer can now produce complex shapes from rhenium—an achievement in technology transfer that is leading to increased availability of higher-quality, lower-cost rhenium parts for both government and industry.

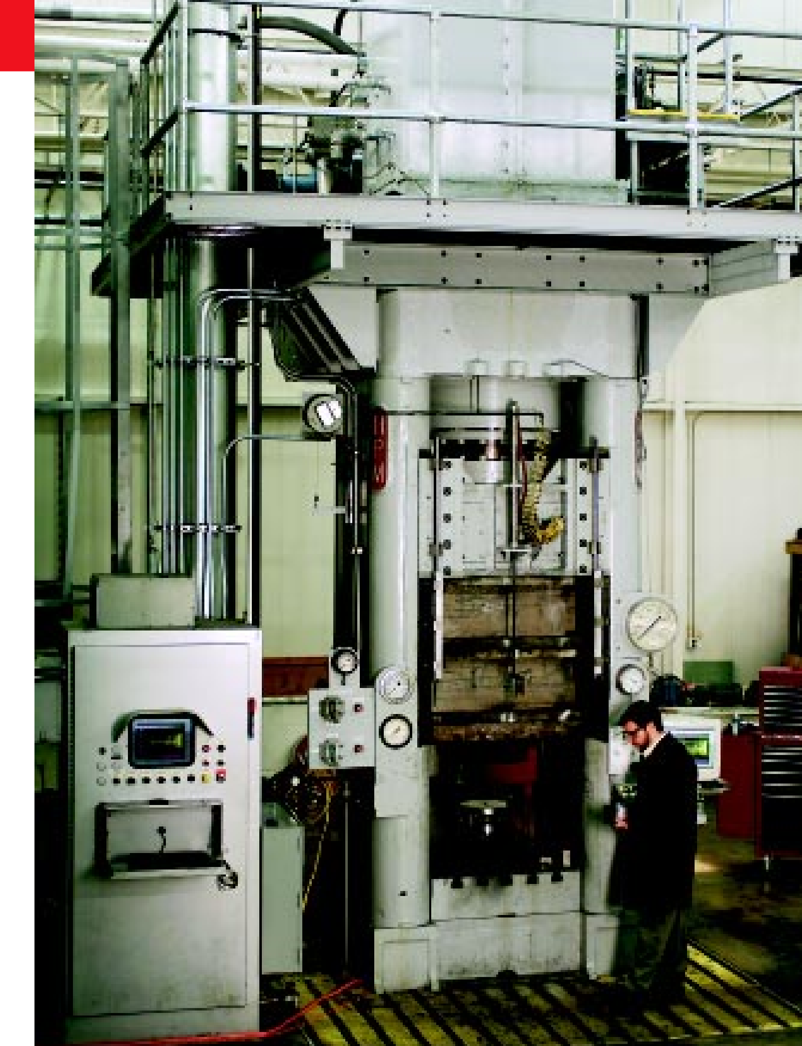
Rhenium, a semi-precious metal, is the material of choice for certain SM-3 precision components that are exposed to very high temperatures. However, rhenium presents a formidable challenge to the process engineer. The material's high stiffness and tendency to work harden make rolling sheet production expensive and render single-point-machining processes impractical.



The NCEMT has pioneered the use of alternative methods for shaping rhenium, including electrochemical machining (ECM) and abrasive water-jet cutting. In addition, fundamental metallurgical studies have been conducted on the deformation behavior of the material, opening up new rolling and forging possibilities. Engineers are now better able to predict the final shape of a part or component. New powder metallurgical techniques such as powder injection molding (PIM) have been used at the NCEMT to mold complex rhenium components, which are then sintered to full density.

All of these improvements to existing powder metallurgy manufacturing methods will contribute to the reduction in the cost of rhenium processing throughout the U.S. industrial base.

Upper right photo: The 850-ton press, one of the most controllable presses of its size in the world, is universal enough to accommodate hydrostatic and conventional extrusion, mechanical testing, forging, custom metal forming and more. Inset: Relying on precise calibrations in the NCEMT Powder Metallurgy Lab.



Powder metallurgy demonstration facility

To demonstrate. Educate. To test and transfer new manufacturing technologies to the U.S. Navy, the NCEMT maintains a state-of-the-art Powder Metallurgy Demonstration Facility. Here, government and industry clients obtain hands-on experience in the latest advances and have the opportunity to test new ideas.

The Powder Metallurgy Demonstration Facility is equipped with a 100-ton powder compaction press, a 110-ton powder injection molding machine, an 850-ton vertical hydraulic press for forging and extrusion, and sintering furnaces. There is also a six-station induction heating system combined with a 600-ton customized die-casting machine for semi-solid metalworking and a superplastic fabrication press. To take advantage of the many advancements in powder metallurgy today, designers need to be aware of the benefits powder metallurgy offers and of the tools available to them. The Demonstration Facility helps answer this need.

Advanced Alloys

Developing, testing and verifying leading-edge ideas

The NCEMT is optimizing traditional and advanced alloys to achieve the highest possible levels of reliability and process efficiency in the production of weapon-system components.

Considerable progress is being made in the fabrication of low-cost titanium. These innovations have a direct impact on the XM777 Lightweight 155mm howitzer (LW155), Joint Strike Fighter and Future Combat System Demonstration Vehicles and broad applicability throughout the U.S. industrial base.

The development of a single-melt, plasma arc cold hearth melting (PAM) process for reduced-cost titanium will ensure good ingot surface finish and sound interior structure. This process will also achieve improved material cleanliness, chemistry control and production rate while utilizing a variety of low-cost feedstock mixes.

Ceramic and an aluminum-lithium alloy have been fabricated to create ceramic armor panels. This achievement can significantly reduce the weight of U.S. combat vehicles.

Titanium alloys exhibit high specific strength and excellent corrosion resistance. These features have the potential to reduce component weight and sustainment cost. However, titanium is very reactive and must be melted and cast into ingots for forging and rolling applications using vacuum arc remelting (VAR), PAM, or electron beam cold hearth melting (EBM). The current industry standard requires double or triple VAR or PAM and EBM followed by VAR. This multi-step requirement increases delivery time and results in higher production costs by restricting the use of recycled machine turnings in the feedstock. Widespread use of titanium alloys, more specifically Ti-6Al-4V, has been limited by relatively high cost as compared to steels and aluminum alloys. Optimization of the single-melt, PAM process for low-cost titanium will remove these historic limitations and enable the production of value-added components for military vehicles.

The NCEMT is also working to develop affordable new manufacturing applications for titanium matrix composites (TMCs) for rotating components (specifically disks and spacers) used in the Joint Strike Fighter F136 engine. TMCs are not only durable, they are light. However, this is the first time the advanced composite has been used for rotating components because of high manufacturing costs and the lack of critical design data. This NCEMT project is enabling the use of the highly durable advanced composite, which can significantly reduce the weight and improve the life-cycle costs of the engine.

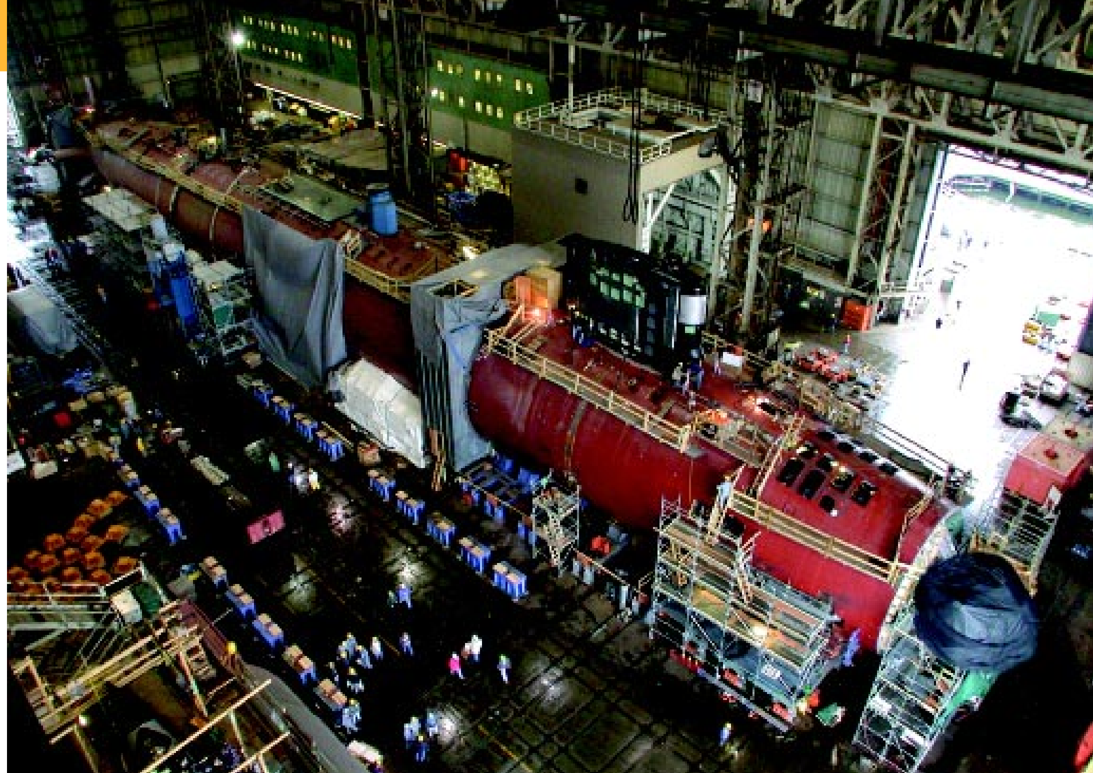
Which material will work best in a given application? The choice is challenging because more than 100,000 materials exist. To select a material that would improve marine-grade fasteners, the NCEMT conducted material property evaluations and characterizations. These studies verified the properties of MP98T®, formerly called MP159® modified, and recommended its use aboard U.S. Navy submarines. This collaborative effort by the NCEMT; Timken Latrobe Steel; SPS Technologies, Inc.; Electric Boat Corporation and the Navy Surface Warfare Center-Carderock Division under the guidance of the Naval Sea Systems Command, Metallic Materials Branch (NAVSEA 05M2) has led to the development of new high-strength marine-grade fasteners for the Virginia-class submarines. These fasteners meet Navy requirements not just for superior corrosion resistance, but for added strength and toughness.

In another project, the NCEMT has been leveraging investments in aluminum-lithium alloys from the space and aircraft sectors to reduce the weight of Department of Defense systems. Aluminum-lithium alloys have proven themselves in the space and aircraft sectors by reducing the weight of complex structures. Lithium reduces density and increases stiffness when alloyed with aluminum, and with proper alloy design, aluminum-lithium alloys can have exceptional combinations of strength and toughness.

Concurrent Technologies Corporation (*CTC*), the organization that operates the NCEMT, designed a lightweight trailer to exploit the exceptional properties of aluminum-lithium alloy 2195 coupled with friction stir welding. The aluminum-lithium trailer has been sprayed with a surface-engineered powder designed to reduce corrosion susceptibility. In addition, the NCEMT designed an armored door for a Future Combat Systems concept vehicle that leverages friction stir welding technology developed earlier for the AAAV project.

The U.S. Army relies on thousands of small trailers to transport equipment and supplies . . . trailers that are in need of modernization. Toward that end, other advanced alloys are also under investigation. *CTC* is collaborating with the Armament Research, Development, and Engineering Center (ARDEC) at Picatinny Arsenal, New Jersey, and with the Center for Composites Manufacturing at the University of Delaware to develop titanium-intensive and composite-intensive concept trailers, respectively.

Innovative new processes and applications for these and other advanced alloys will meet immediate defense needs as well as those of the future force.

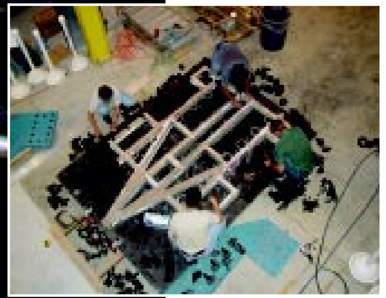


The NCEMT assisted in creating new high-strength fasteners for the Virginia-class submarine shown here under construction.

Alloys improve ballistic performance

Because future combat will require lighter and more mobile systems, work is being accelerated to develop radically new weapon systems that will give the U.S Army not only firepower and speed, but also flexibility to move in non-conventional battlefields, such as cities and suburbs. One way in which the NCEMT is supporting the effort is through the implementation of advanced alloys that will decrease the weight of combat vehicles.

Engineers and scientists at the NCEMT and Concurrent Technologies Corporation have successfully fabricated composite armor panels using a combination of ceramic and aluminum-lithium alloy 2195. These panels have a temper specifically balanced for optimal ballistic performance, strength and corrosion resistance. Much of the information regarding the project is classified; however, it can be reported that this composite armor has the potential to reduce weight relative to conventional armor systems, and it will be highly competitive with other advanced-armor systems in development.



The NCEMT's Friction Stir Welding system, one of the largest in the world, can accommodate a full-size combat vehicle.
Inset: The NCEMT designed a concept Army trailer that is manufactured from aluminum-lithium alloys using friction stir welding.

Joining

New ways of thinking to support new ways of fighting

The NCEMT supplies forward-thinking metalworking solutions to support the most advanced weapon systems. For example, the NCEMT, the Tank Automotive Research, Development, and Engineering Center (TARDEC) and Concurrent Technologies Corporation (*CTC*) have been effecting the technology transfer of friction stir welding to combat vehicles. Replacing conventional welds with friction stir welds could significantly improve the strength, ductility and survivability of weapon systems.

Friction stir welding is a revolutionary, environmentally friendly, solid-state welding technology invented in 1991 by The Welding Institute in the United Kingdom. In friction stir welding, materials to be joined are clamped together; a non-consumable, rotating pin tool is plunged into the joint line and traversed along the joint. Heat generated from the rotating pin and from the tool shoulder rubbing against the materials that are being joined softens the metal so that it flows plastically, creating a welded joint. Since no discernable melting occurs, problems with hot cracking and shrinkage porosity are eliminated. The process accomplishes solid-state welds in many metals, such as aluminum, copper, lead, magnesium, steel and titanium alloys.

Amazing progress in friction stir welding techniques has led to numerous advantages over conventional fusion welding. In addition to superior strength and ductility, these advantages include significant reduction in residual stresses, elimination of filler wire, greatly simplified weld preparation procedures, and reduced environmental health and safety concerns. Moreover, alloys that were "non-weldable" by fusion welding techniques can now be friction stir welded.

Al-Cu 2519 is one example of an alloy that has been shown to be friction stir weldable. This finding is extremely beneficial to the design of the U.S. Marine Corps' Advanced Amphibious Assault Vehicle (AAAV).

The AAAV, one of the major new combat vehicles under development, is expected to be launched from a ship and travel in littoral waters at speeds of up to 25 knots. Upon reaching shore, it will be able to switch to ground-transport mode. An armored personnel carrier, the AAAV must achieve the highest degree of mobility, survivability, lethality and reliability—all at a minimal weight. The main structural alloy for the AAAV is Al-Cu alloy 2519, which displays weldment cracking during ballistic impact of butt joints.

The NCEMT and its partners proposed that friction stir welding replace conventional fusion welding on the AAAV. In 2003, the friction stir welds for the AAAV passed the mine-blast test—a milestone in the development of the combat vehicle and the final challenge that the 2519 welds had to pass. Since the project's inception, NCEMT scientists and engineers have produced welds that progressively achieved the following:

- A weldment tensile strength 47 percent higher than the minimum weld strength obtained by gas metal arc welding
- An increase in weldment ductility by more than a factor of three
- A passing score on the ballistic shock impact test. The welds attained significantly higher velocities than the 1946 Mil Spec requirement—until then, a test never passed by conventional gas metal arc butt weldments of alloy 2519.

To accommodate structures the size of the AAAV, the NCEMT has designed and installed one of the largest friction stir welding systems in the world and the only one specifically built to fabricate a full-size combat vehicle. This three-story system is an excellent research-and-development aid for friction stir welding. The system can perform welds in up to 2-inch thick aluminum armor plate in a single pass within a 26-foot by 13-foot envelope.

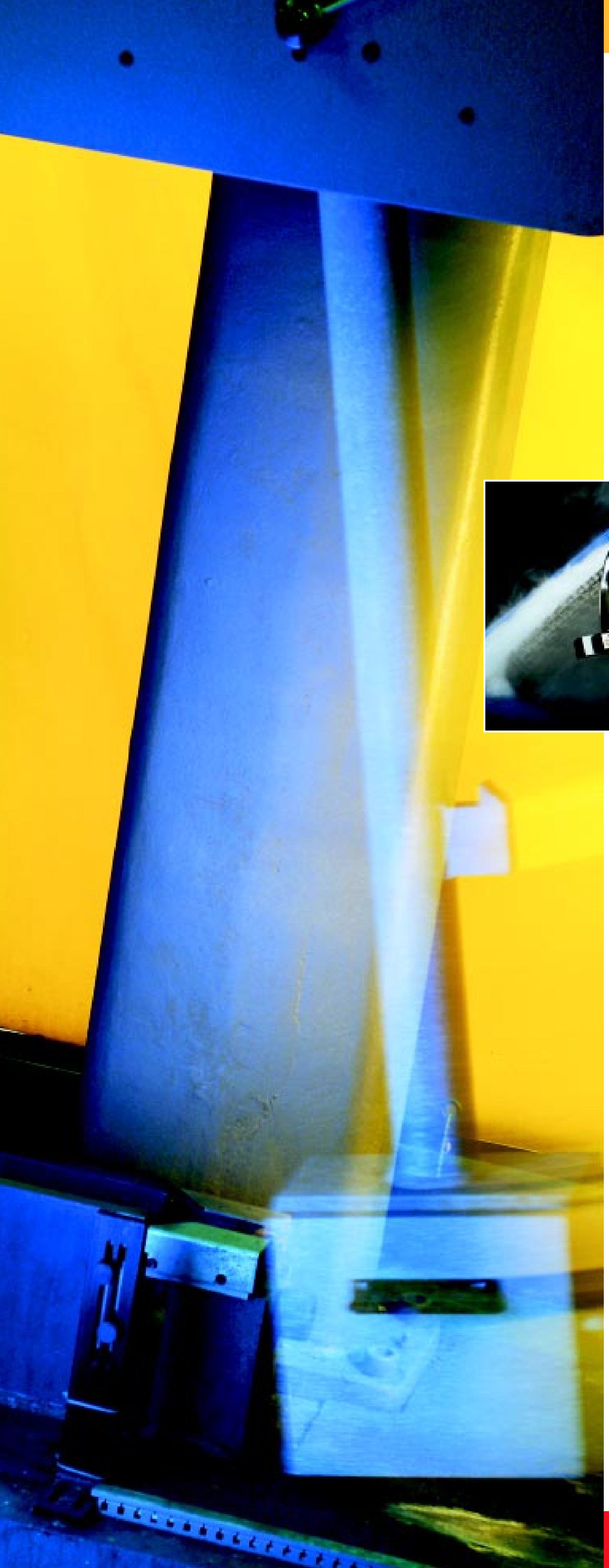
The new welding system fills a critical need for research, development and prototyping of large structures. The pioneering welding technique offers many advantages over arc welding techniques, but the large capital investment associated with this type of equipment has slowed its use in the manufacture of large combat vehicles. The NCEMT, TARDEC and *CTC* have taken the bold step of installing this system to provide a prototyping capability for combat vehicles, making it possible for prime manufacturers to explore the benefits of friction stir welding for their applications before installing their own systems.

Procedure development of Submerged Arc Welding (SAW) takes place within the NCEMT Welding Laboratory.

Structure is largest attempted to date

In 2003, an aluminum combat-vehicle hull mine-blast test article, built by *CTC* in partnership with General Dynamics Land Systems (GDLS) for the Future Combat System Program, became the largest friction stir welded combat-vehicle structure attempted to date.

The lower portion of this test article employs friction stir welds in all of the main aluminum-alloy structural joints, making it an unprecedented demonstration of friction stir welding for large structural applications. The prototype structure will undergo mine-blast testing to determine its response to the explosive force of a land mine. *CTC* developed the welding tools, fixtures and techniques for construction of the test article, demonstrating that friction stir welding can be used to construct large, complex structures with high joint strength and ductility.



Joining continued

The NCEMT has also developed new tool designs that make friction stir welding more attractive for production. Using these new tools, the NCEMT has produced welds in 1-inch thick alloy 2519 at up to 4 inches per minute—a milestone that far exceeded the target set by the prime contractor. In addition, these new tool designs have decreased welding loads from approximately 16,000 pounds to 9,000 pounds, greatly reducing the forces carried by the friction stir welding equipment.

New ideas are important in the drive to support new ways of fighting. The U.S. Army uses thousands of small trailers that are towed into the battlefield carrying a variety of equipment and supplies. However, these trailers are in need of modernization to keep pace with upgraded Army vehicles. The NCEMT has created a revolutionary concept trailer that employs very high-strength aluminum-lithium alloys coupled with state-of-the-art friction stir welding technology. This trailer may be the prototype for U.S. Army trailers that can support the mobility of Future Combat Systems vehicles. The one-of-a-kind aluminum-lithium trailer premiered at the AUSA (Association of the United States Army) Annual Meeting in October 2003.

In addition to increased durability and corrosion resistance, the new aluminum-lithium trailer can easily be redesigned to accommodate varying load paths. The aluminum-lithium trailer is a monocoque structure—one that uses skins separated by stiffeners to carry the load. NCEMT engineers and scientists friction stir welded aluminum-lithium skins to aluminum-lithium I-beams to form a stiffened structure that offers incredible design flexibility and structural integrity.

The Charpy impact test is one method used to characterize material properties. Inset: Charpy specimen being cooled in an alcohol bath to determine material properties at various temperatures.

USS Harry S. Truman (CVN 75). NCEMT-driven advancements in metalworking technology help to ensure that the U.S. fleet continues as the unchallenged world leader.

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